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The Impact of Replacement Windows on Heating-Load, Overheating, and Air Quality of Classrooms of Victorian Schools

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Abstract: This work provides an assessment of the effect of double-glazing the windows of Victorian schools on indoor-air-quality, overheating, health and students' satisfaction, and heating demand. The data collected from instruments and questionnaires during a winter period from a refurbished Victorian school with double-glazed windows and another non-refurbished one with old sash windows were compared in order to analyse the indoor-air-quality and the students' satisfaction and wellbeing. Computer simulations were used to study overheating and heating demand. This study shows that double-glazing the Victorian schools saves 30-50% of annual heating energy. However, it also deteriorates the environmental conditions in the schools by making them at least 12-24% more prone to overheating, more susceptible to mold growth and health issues by 5% and increases CO_2 levels within classrooms by 33%. Due to bad environmental conditions, students tend to complain more in double-glazed Victorian schools, thereby balancing out the energy gains obtained through double-glazing.

Keywords: Heating demand, Indoor Air Quality, Overheating, Classrooms, Victorian schools

1 Introduction

Good thermal conditions and air quality have an important impact on the academic efficiency of students. One of the dominant features of classrooms is their dense occupancy level. Classes are therefore prone to overheating, due to high internal gains from their occupants. On the other hand, internal emissions such as body odour, water vapour and CO_2 increase concerns on the state of air quality. Providing good ventilation in schools has always been an important issue with regards to diluting pollutants and controlling temperatures. According to current guidelines, the provision of the minimum amount of 3l/s with the capability of achieving 8l/s has been therefore suggested for schools (Building Bulletin 101, 2012). Historically, buildings have relied on air leakage to provide fresh air. However, after the oil crises of 1970s, in order to save energy, new regulations in terms of improvement in building fabric and airtightness were set. As buildings became more airtight, background ventilation became an important issue for keeping our buildings healthy, providing minimum Indoor Air Quality requirements, and preventing summer overheating.

Replacing single-glazed windows with double-glazed ones results in a considerable amount of energy saving in a small period of time. Therefore, replacing windows is the most common act which occurs in 65% of the retrofitting measures of educational buildings (Barton et al, 2007). On the other hand, research done on UK dwellings shows that replacing old windows can reduce ventilation levels below recommended levels unless trickle-vents is installed at the same time. In a study on office buildings'

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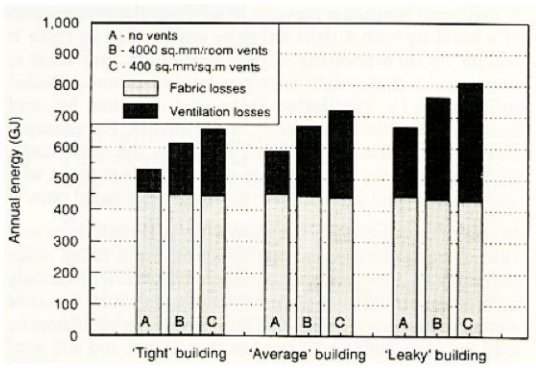
trickle-ventilators performance, three types of buildings with the following characteristics were analysed: Tight with mean infiltration rate of 0.12ach, Average with a mean infiltration rate of 0.23ach, and leaky with a mean infiltration rate of 0.38 ach. The results show that adequate air-quality may be achieved through the adoption of proper trickle-ventilation; however, there won't be any energy savings due to ventilation heat-loss.(White et al, 1998, p.4) The only advantage that a double glazed window with trickle-vent will have in terms of energy efficiency is that of an improvement in U-values. Although this is good in terms of reducing heating load during the heating season, the improvement in building fabric in places with high internal gains like classrooms can lead to overheating during summertime (Jenkins et al, 2009, p.490).



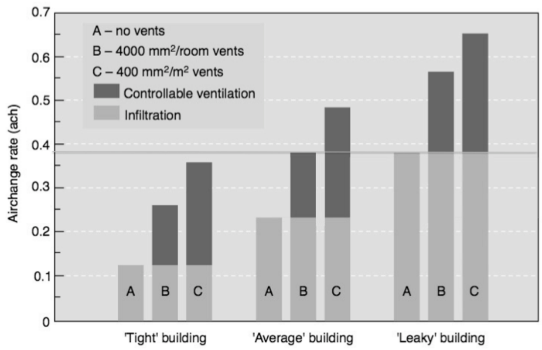


Figure 1.1 Comparison in ventilation heat loss (Perera et al, 1993, p.85). Figure 1.1 Comparison in air change rate (White et al, 1998, p.4).

Schools present up to four-times higher occupancy per unit area than a normal office. BBL 101 has mentioned that trickle-vents alone would not be sufficient for providing adequate background ventilation in classrooms. Typical Victorian classrooms have an area of 40-70m^2 and a height of 4-5m. If we take the average volume of classes, the average volume of typical Victorian school classes is 250m^3, which indicates that the required air-change-rate is 1.15ach and the minimum acceptable level is 0.4ach. Looking at the figure above, leaky Victorian buildings would be almost able to provide the acceptable ventilation rate; however, it would require trickle-vents to provide the recommended ventilation levels when windows are closed. The following question therefore arises: how much will new windows reduce heating demand, and what is their impact on indoor-air-quality, overheating and students' satisfaction?

2 Methodologies

Two similar Victorian primary schools in North London were chosen as a case study, one of which had replaced its old single-glazed windows with trickle-vented double-glazed ones. To study the successfulness of this retrofitting measure in terms of air-quality and students' satisfaction, three classrooms on the second floor of each building were chosen as a sample for assessing the environmental conditions of the school. The air-quality of these classrooms and the relevant occupant behaviour were monitored during five working days in the autumn. During the observation week, students of the selected classes were asked to fill in a questionnaire and rate therein the environmental conditions of their school. In order to assess the effect of double-glazing on annual heating-demand and overheating, the buildings were simulated.

2.2 Data used in simulation

The CO_2 data collected from classrooms and their exterior was used to calculate the infiltration rate of schools through the CO_2 decay method. Considering all the variables, the air change rate calculated for double-glazed school of Duncombe was calculated to be 0.16ach, whereas it was 0.29 ach in Yerbury Primary school, which possessed old single-glazed sash windows.

The heating demand with different types of glazing in both schools was simulated for the duration of school working hours, subtracting the national UK school holidays and weekends. The models were simulated without defining any opening for windows or doors, because as observed during the field study, windows were shut during the heating season. Overheating was studied under different scenarios, such as the use of night ventilation and the use of blinds, and the average of all results was used to derive the final conclusion. For overheating study, the models were simulated by defining an opening schedule for the windows and doors during school hours.

3 Results

3.1 Results achieved from the instruments installed in sites

The average level of CO_2 when occupants were present in the classrooms of non-refurbished school was 1496.39ppm, which falls within the acceptable level of up to 1500ppm. However, the frequency of CO_2 levels in occupied periods shows that half the time, the amount of CO_2 exceeds this minimum recommended amount. The average CO_2 level during occupied hours in sample classrooms of Duncombe is 2255.49 ppm, which significantly exceeds the minimum permissible levels. From an analysis of the data gathered from the schools it can be inferred that the humidity levels for Duncombe are higher than the non-refurbished school. The amount of relative humidity levels exceeded 60% during 4.2% of the time of the observation week, which can indicate the possibility of the risk of mold growth. Although part of this difference may be attributable to a slight increase of 0.18 m^2/p in the occupant density in Duncombe, the fact that the humidity and CO_2 generated inside the classrooms of Duncombe cannot move towards the exterior because of higher airtightness of double-glazed windows causes an increase of about 5% in Relative-humidity and 33% in CO_2 concentration levels.

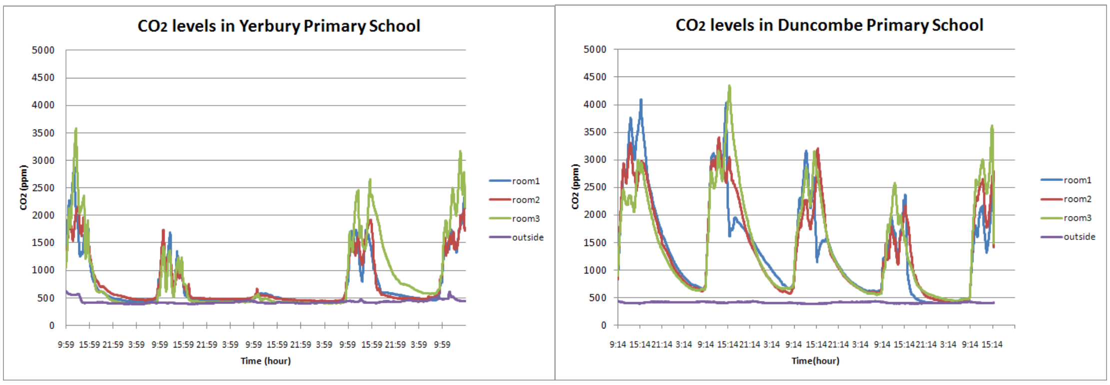


Figure 3.1: CO_2 levels in Yerbury and Duncombe primary schools during the observation period.

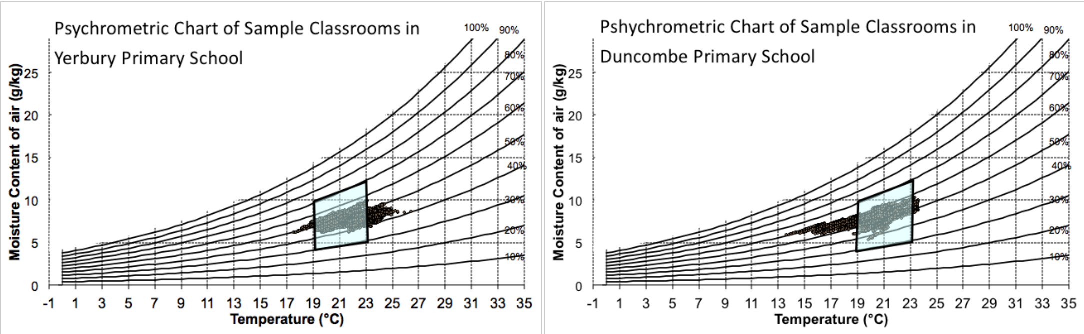


Figure 3.2: Psychometric charts of the classrooms during the school hours of observation weeks.

3.2 Results from student questionnaire

In general, meaningful correlations are found in terms of air quality and its effects when comparing Duncombe primary school to Yerbury. The most powerful correlation when comparing the student answers of the two schools was to be found in the response to the hypothesis that poor air quality can impair learning performance. In Duncombe, this question had 26.3% more positive responses and 28.7% less negative ones when compared to Yerbury. Indoor-air-quality receives 23.1% lower marks in Duncombe when compared to Yerbury. Although the perception of smell is 19.8% higher in Duncombe, the perception of stuffiness is lower by 20.1% in this school. Studies have shown that people conceive the air to be fresher at lower enthalpies (Awbi, 2003, p.43). The reason why students were thinking that air was fresh in Duncombe was mainly due to the cooler temperatures present there.

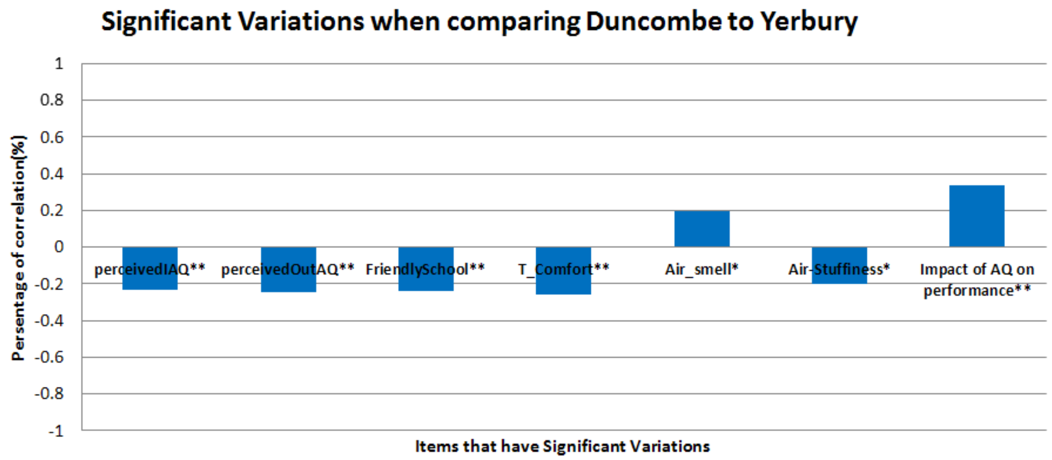


Figure 3.3: Significant variations when comparing Duncombe primary school to Yerbury.

3.3 Results of modeling the heating demand in schools

The results show that double-glazed windows bring about a reduction of 48,05%-48.56% in Yerbury and of 29.78%-29.87% in Duncombe. Studies on the impact of energy saving in the teaching areas of the schools have shown that the need for heating in classrooms is reduced by 54.4% in Yerbury and by 34.5% in Duncombe in the case of the adoption of double-glazing.

Table 3.1: Percentage of decrease or increase in heating-demand due to double-glazing or single-glazing in Yerbury and Duncombe

	HEATING-MW.h(TRY)	HEATING-MW.h(DSY)	Classroom1	Classroom2	Classroom3	Computerroom	Classrooms G	Classsrooms F	Classrooms S
YERBURY(Single-glazed,0.29ach)	93.53	88.51	1.26	1.16	1.21	1.66	4.66	5.52	3.82
YERBURY(Double-glazed,0.16ach)	48.59	45.53	2.51	2.55	2.66	3.75	10.38	13.16	7.32
Reduction in energy due to double-glazing	44.94	42.98	1.25	1.39	1.45	2.09	5.72	7.64	3.5
Percentage of reduction due to double-glazing	48.05%	48.56%	49.80%	54.51%	54.51%	55.73%	55.11%	58.05%	47.81%
Percentage of increase due to single-glazing	92.48%	94.42%	99.21%	119.83%	119.83%	119.83%	119.83%	119.83%	119.83%
DUNCOMBE(Double-glazed,0.16ach)	69.81	66.62	2.76	2.74	3.05	1.81	17.04	13.07	2.76
DUNCOMBE(SINGLE-glazed,0.29ach)	99.54	94.86	1.84	1.66	2.06	0.96	11.93	8.14	1.72
Reduction in energy due to double-glazing	29.73	28.24	0.92	1.08	0.99	0.85	5.11	4.93	1.04
Percentage of reduction due to double-glazing	29.87%	29.78%	33.33%	39.42%	32.46%	46.96%	29.99%	37.72%	37.68%
Percentage of increase due to single-glazing	42.50%	42.40%	50%	65.06%	48.06%	88.54%	42.83%	60.56%	60.46%

3.4 Modeling the possibility of overheating in schools

The impact of double-glazing on overheating shows that the number of hours in which the temperatures are above 28°C increases by 4.29-8.2% in Duncombe and 18.67-24.16% in Yerbury. Considering the teaching areas, this increase is between 15.98- 23.56% in Duncombe classrooms and 12.94-14.26% in Yerbury's classrooms. While double-glazing doesn't have any impact on the maximum classroom temperatures in Duncombe, its effect in Yerbury is 0.46%. Taking global warming into consideration, the average maximum temperatures in Duncombe decrease by 1.43%, despite increasing by 1% in its classrooms. Furthermore, there is an increase of 0.59% in Yerbury and 0.45% in its classrooms.

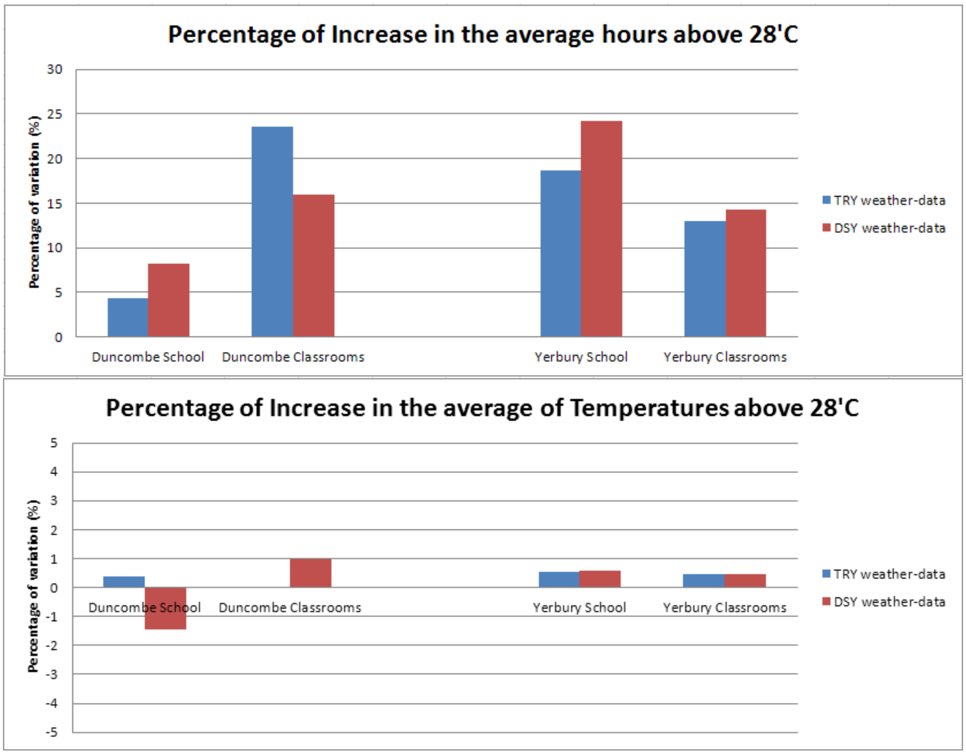


Figure 3.4:Percentage of increase in temperatures due to double-glazing.

4 Discussion

Based on the previous analysis, it may be concluded that double-glazing brings about a reduction of between 30-50% on heating demand, dependent on the amount of glazed areas. The heating savings through double-glazing the windows in the classrooms of Yerbury was 54.4% compared to 34.5% in Duncombe. This was due to the fact that Yerbury's classrooms had slightly larger windows and their orientations were towards north. Studies have shown that, although double-glazing saves energy, it also impairs the schools' environmental standards in terms of health, indoor air quality, students' satisfaction and summer overheating.

Overheating studies have shown that the chances of having more hours above 28°C increases by 12-24%, and having warmer maximum temperatures increases up to 1% in the learning areas of naturally ventilated Victorian schools if the window structure of these schools is modified due to double-glazing. Accordingly, the chances of learning problems due to high temperatures will be higher in double-glazed classrooms. The analysis done on the data collected from the classrooms of the double-glazed Duncombe and the single-glazed Yerbury shows that double-glazing the Victorian schools results in an increase of about 33% in the classrooms' CO_2 concentration and 5% in relative-humidity quantities. By taking into account higher CO_2 levels as well as the possibility of high temperatures in classrooms, the students' learning-ability and their well-being in double-glazed schools will be severely affected. The questionnaires' results also showed more complaints with regards to air quality in the double-glazed school of Duncombe, with 33.9% more agreeing on a direct relationship between air-quality and learning, compared to the student responses from the single-glazed one of Yerbury.

However, all the statistics mentioned above may vary from reality due to the limitations in this study, which are uncertainties in the occupants' behavior and their exact presence in classrooms in modeling, variations in the building's infiltration rates which may be caused by wind and different temperatures, and the impact of other factors on student answers in questionnaires.

5 Conclusions

This study shows that the only positive outcome deriving from the replacement of the old sash windows with double-glazed ones is the energy saving benefit. However, the sum of negative effects of double-glazing falls within the range, which is more than its positive influence. This measure increases the chances of overheating, health issues due to mold growth, and higher CO_2 levels in classrooms. Sash windows in these Victorian schools are also part of their historical heritage. Careful consideration should therefore be adopted prior to investing considerable amounts of money on double-glazing these schools as an energy-saving measure. More studies should be undertaken to understand the impact of energy saving measures on the environmental conditions of schools.

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